Predictability Assessment and Improving Ensemble Forecasts

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PROJECT GOALS AND OBJECTIVES

The PI continues to examine atmospheric predictability with the goal of improving ensemble forecasts at ranges of 12 hours to 10 days. The research is addressing several issues, including:

1. Documentation of analysis uncertainty from mesoscale and global analyses.
2. Design of optimal ensemble forecast systems (EFS), with an emphasis on precipitation forecasts.
3. Calibration of EFS output by artificial neural networks and other statistical techniques.
4. Design of stochastic physics parameterizations that improve under-dispersion in EFS's.

Most progress during the past year involved topics 1 and 2, with limited progress on topics 3 and 4, so descriptions of new results will primarily emphasize topics 1 and 2. The PI also served as Co-Chief Scientist to Dr. M. Steven Tracton for ONR initiative on Predictability in the Atmosphere and Ocean, and presumably will continue to play some role on any follow-up ONR predictability initiative.

DOCUMENTATION OF ANALYSIS UNCERTAINTY

As noted in last year's report, we are estimating the statistics of analysis errors Eo from differences between different analysis-forecast systems. The method gives a "component" of the analysis uncertainty that, although difficult to relate with high precision to Eo, quite likely denotes a reasonable lower bound of its magnitude. Although this methodology is not as comprehensive or precise as statistics from emerging ensemble data assimilations or from well-constructed observing system simulation experiments (OSSE's), it is currently tractable, *very* economical, and useful guidance can be quickly obtained.

PI continued collaboration with DRI participants Errico (NASA/GSFC), Baumhefner and Tribbia (NCAR) to document analysis uncertainty in global analyses. Analyses from ECMWF and NCEP are being compared and similar statistics are being computed for the global difference fields, and now includes moisture and decomposition of the wind fields. This work is the natural complement to the ongoing LAM documentation. A 2D spectrum is shown in Fig. 1 for 700 mb temperature and 700 mb specific humidity, fields that exhibit markedly different characteristics.

The variance for the difference between analyses is as large as the variance for ECMWF fields for wavenumbers higher than 32 and 24 for temperature and moisture, which indicates *global analyses of moisture contain uncertain information for wavelengths shorter than 12-15^o latitude (1,600-2,000 km)*.

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Moreover, those scales for which the analysis variance (wavenumbers 3-15) clearly exceeds the difference variance only run a factor of 2-3 larger for moisture, indicative of overall *low confidence for*

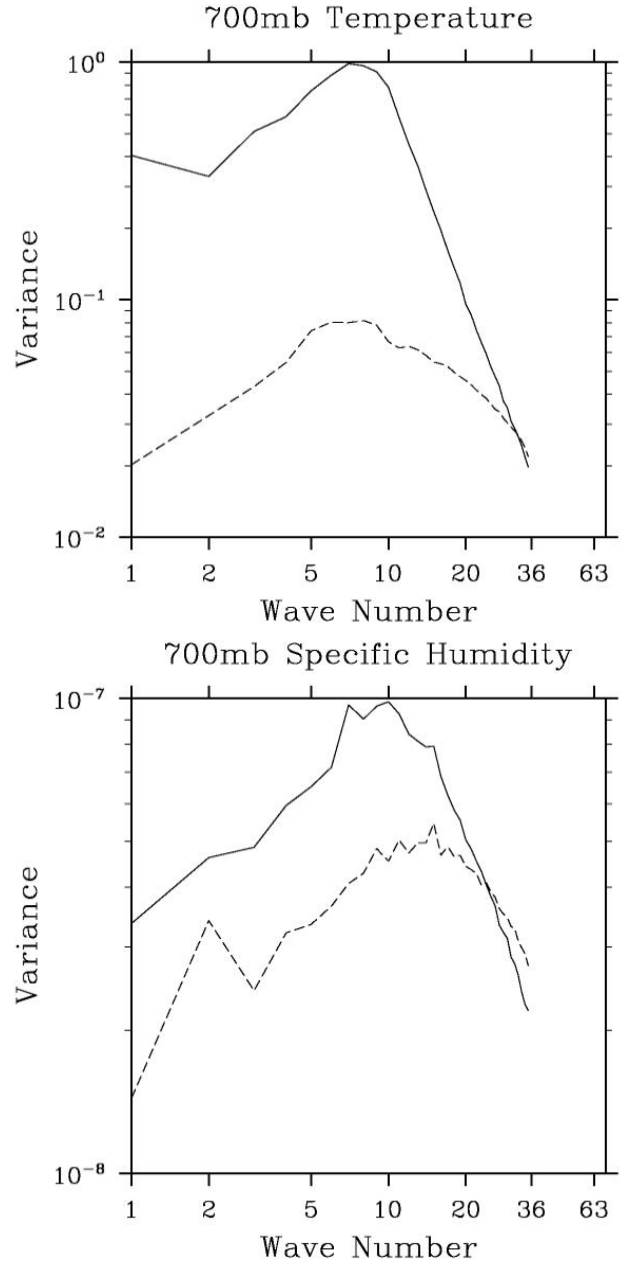

Fig. 1. Two-dimensional variance spectra for 700 mb temperature (top) and specific humidity (bottom), averaged for the boreal 1990/91 winter (DJF) and 1991 summer (JJA). Spectra for differences between ECMWF-NCEP global analyses (dash) and for ECMWF analyses (solid).

moisture analyses. Fig. 2 gives the zonal average of the distribution of the standard deviation of the differences for the temperature and moisture. Temperature variance is clearly largest over the southern hemisphere. (Values between 1000-700 hPa over Antarctica should be ignored owing to excessive extrapolation below the surface.) Moisture variation is largest over the tropical lower troposphere. In terms of contributions to moist static energy, the uncertainty from specific humidity dominates that

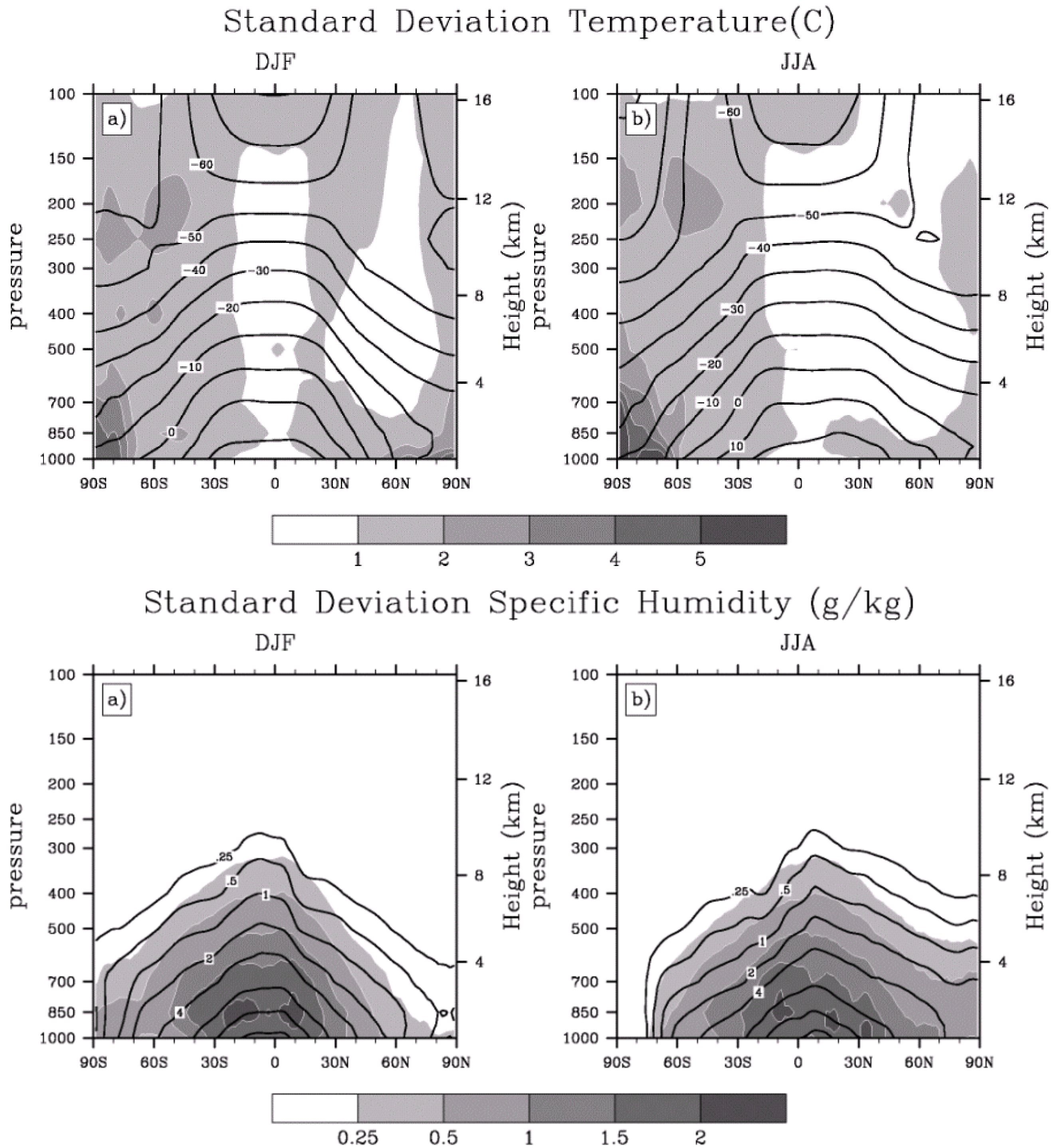

Fig. 2. Zonal average of the standard deviation (shade) of temperature (top) and specific humidity (bottom) differences for the 1990/91 boreal winter and of the corresponding ECMWF analyses (contours). In terms of moist static energy, 1 gm/kg specific humidity corresponds to 1 K.

from temperature in the lower troposphere of low-latitudes. Aloft, temperature differences begin to dominate, as would be expected from the Clausius-Clapeyron equation.

The PI has completed 16 pages of a first draft for a manuscript that will report these results.

MESOSCALE, ENSEMBLE FORECASTS OF PRECIPITATION OVER THE WESTERN U.S.

Under ONR support, the PI is collaborating with members of the Hydrology Dept. to examine the performance of mesoscale ensemble forecasts of precipitation. A 12 km grid point equivalent of the NCEP Regional Spectral Model (RSM) was run twice-daily for the 2002-2003 cool season over the Southwest U.S. Initial and lateral boundary conditions were supplied by global ensemble forecasts from the NCEP Global Forecast System (GFS). Eleven RSM members were run for the region shown in Fig. 3. Although a smaller than desired region owing to lack of computing resources, its impact on damping ensemble dispersion would be minimized for precipitation. Verification was performed over the aggregate shaded region, and the four individual hydrological districts that possess unique climatologies.

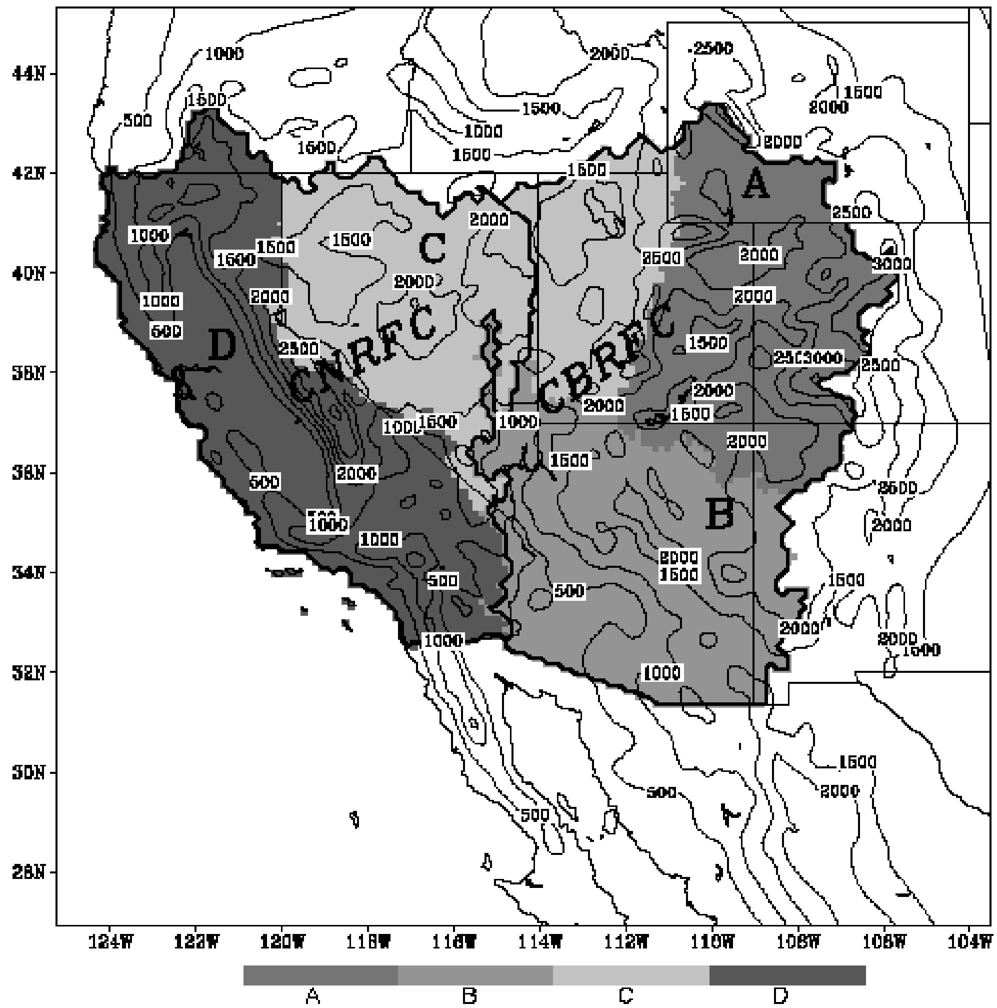

Fig. 3. RSM domain (163 x 172 grid points, 12-km mesh) and topography (contour interval 500 m). Four USGS hydrologic regions (shaded area): A--Upper Colorado Region, B--Lower Colorado Region, C--Great Basin Region, and D--California Region. The four regions possess unique climates and model performance characteristics.

A summary of the most significant results can be gleaned from Fig. 4, which shows the distribution of the Ranked Probability Skill Score, relative to local sample climatology, for 24-h forecasts starting from 0000 UTC and 1200 UTC initial conditions. First, forecast skill exhibits a strong spatial dependence. The windward ranges of California exhibit the highest skill, whereas the western U.S. shows no or low skill over vast regions of the interior deserts and mountains. Analysis of the correlation coefficient between the RPSS and the density of rain gauges reveals a significant, positive correlation. This suggests that observational and analyses uncertainty is playing an important role in the assessment of skill. The relevance of these findings to the Navy's battle space environment is obviously. There is also weak, but statistically significant, tendency for the 0000 UTC cycle to produce

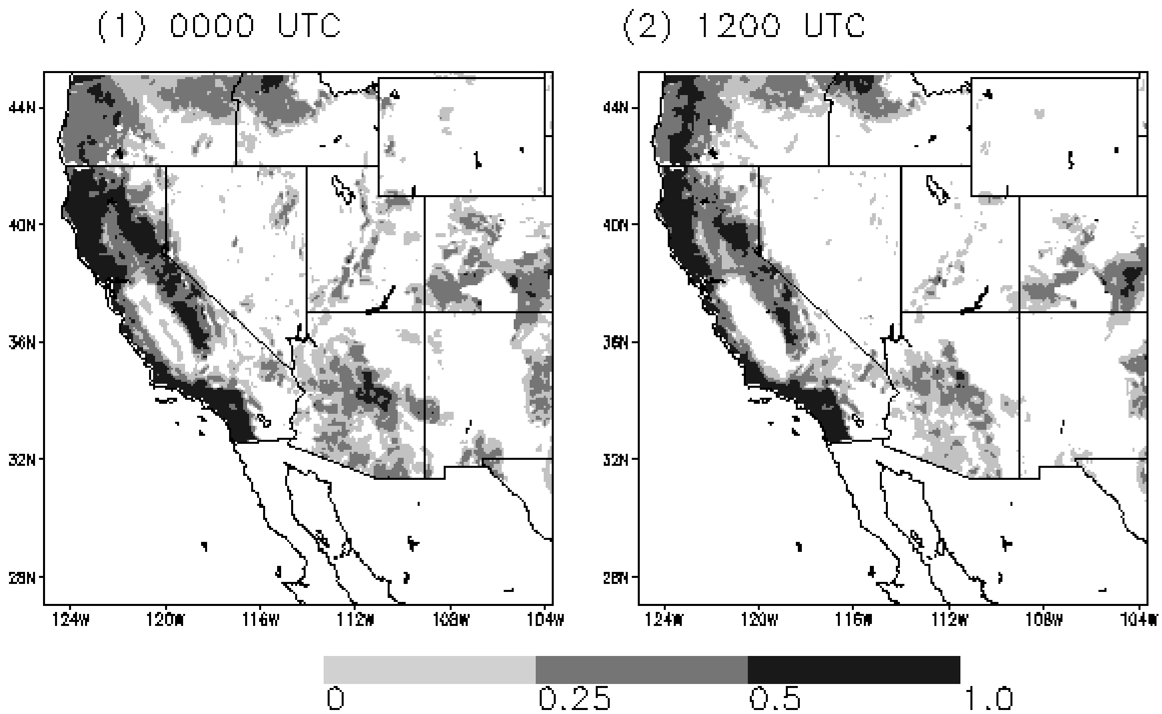

Fig. 4. Distribution of the Ranked Probability Skill Score for 24 h precipitation at (1) 0000 UTC and (2) 1200 UTC cycle. Higher skill is exists over the windward ranges of the West Coast, and 0000 UTC cycles. Four thresholds (1, 10, 20 and 50 mm) were used to compute the scores.

more skillful forecasts, perhaps because of the more accurate initial conditions over the East Pacific Ocean at 0000 UTC that might be related to the increase in surface ship reports and visible cloud track winds.

A first draft of the paper has been completed, and a finalized version will be submitted to an appropriate AMS journal within two months.

POST-PROCESSING OF ENSEMBLE FORECAST PRODUCTS

Calibration of ensemble output with artificial neural networks (ANNs) was expanded to include the ECMWF Ensemble Prediction System (EPS) over the past two years. There has been only limited progress for this project in FY03. To remedy the situation, a Ph.D. graduate student (Arun Kumur) from the Department of Computer Sciences with expertise in neural networks was hired this August under N00014-99-1-0181 to work with the PI in FY04. I anticipate faster productivity with an expert to

perform the coding and graphical duties. I also am scheduling a trip to ECMWF and to discuss with collaborator R. Buizza acquisition of other EPS fields to use as predictors in a multivariate approach and future interest in continuing our collaboration.

I will also be collaborating in FY04 with Dr. L. Smith (Oxford), a peer scientist of the ONR Predictability DRI, to examine a new method to calibrate ensemble forecast.

STOCHASTIC PARAMETERIZATION

A ubiquitous shortcoming of ensemble forecasts, at all time projections, is under dispersion. Ensemble forecasts enclose observations at a frequency less than that expected by chance. The behavior is especially systemic for precipitation. The failure is related, in part, to improper spatial and temporal variance in NWP models. As a way to correct this model error, the addition of stochastic forcing to operational NWP models has been proposed to account for the effects of missing sub-grid scale variability on the grid resolvable scales.

To address the issue of incorporating stochastic cumulus and boundary layer schemes into the limited-area WRF model, a new Ph.D. candidate, Mr. Shawn Rossi (M.S. Atmospheric Sciences 1998), is now being partially supported by N00014-99-1-0181. Mr. Rossi is currently working to complete a set of preliminary ensemble tests with the WRF modeling system by the end of year 3 for an implementation of the stochastic Kain-Fritsch scheme using statistics from the NEXRAD temporal correlation estimates. We will be examining the impact of adding a stochastic term to the specification of the updraft or cloud radius, the KF parameter that exhibits the most sensitivity to small changes in its value (J. Kain, personal communication via D. Bright) and for which available Lagrangian estimates from radar observations offer relevant guidance.

We are focusing on observed statistics and model performance for the West U.S., a desert region with severe surface heterogeneity and a climate similar to the Middle East. The region during the summer is characterized by frequent convection in environments of weak synoptic forcing, but NWP forecasts of precipitation are very poor. For these reasons, the West offers a rigorous, and battle space environment relevant, arena to test the potential merit of stochastic cumulus parameterizations in mesoscale models.

LONG-RANGE PLANS

Over the past three years, the PI was the sole person funded by N00014-99-0181. Because of 1) my obligations as Department Head (appointed 1 Jan 2002), 2) personal health issues, and 3) family reasons (prolonged illness and subsequent deaths of my father in-law and mother), I was unable to use resources over the past three summers at the projected rate. Moreover, Prof. Mary Poulton, the project's neural network expert who was scheduled to be funded for years 1-3 at one summer month per year, was unable to participate in year 3 after she was appointed Head of the Department of Mining and Geological Engineering. This caused the entire burden of running the neural network programs to fall on the PI. As a consequence, much work remains to fulfill the goals of the proposal. For these reasons, I was granted a 12-month no-cost extension by ONR.

The long-range plans for extended final year of the grant are for the PI to complete the first round of post-processing project with student Arun Kumur, begin preliminary testing of a stochastic KF cumulus scheme with candidate Shawn Rossi, and complete the ECMWF-NCEP analysis difference

project. A letter of intent will be submitted to ONR early in FY04 that outlines plans for a new proposal that will request support beginning in late FY 04 or early FY05.

PUBLICATIONS (IN PREPARATION)

Yuan, H., **S. L. Mullen**, X. Gao, S. Sorooshian, J. Du, and H.-M. Juang, 2004: Verification of quantitative precipitation forecasts over the Southwest United States during winter 2002-2003 from a high-resolution version of the RSM ensemble system. To be submitted to *Wea. Forecasting*.

Mullen, S. L., R. M. Errico, D. B. Baumhefner, and K. Raeder, 2004: An estimate of analysis uncertainty from analysis differences. To be submitted to *Wea. Forecasting*.

IN-HOUSE/OUT-OF-HOUSE RATIOS

All research is 100% out-of-house.